

This Page Is Inserted by IFW Operations
and is not a part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

**As rescanning documents *will not* correct images,
please do not report the images to the
Image Problem Mailbox.**

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau



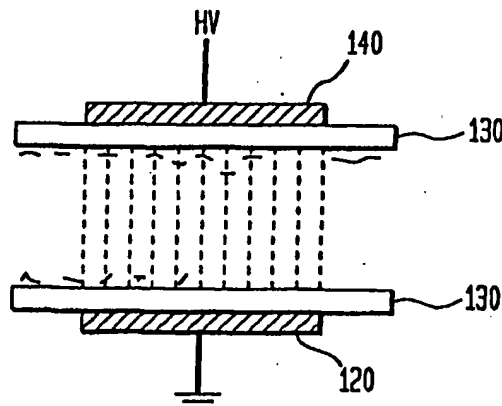
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification 6 : H01J 17/49</p>	<p>A1</p>	<p>(11) International Publication Number: WO 00/16367</p> <p>(43) International Publication Date: 23 March 2000 (23.03.00)</p>
<p>(21) International Application Number: PCT/US99/21147</p> <p>(22) International Filing Date: 15 September 1999 (15.09.99)</p> <p>(30) Priority Data: 09/153,395 16 September 1998 (16.09.98) US</p> <p>(71) Applicant: THE TRUSTEES OF THE STEVENS INSTITUTE OF TECHNOLOGY [US/US]; Castle Point on Hudson, Hoboken, NJ 07030 (US).</p> <p>(72) Inventors: KUNHARD, Erich, E.; 807 Castle Point Terrace, Hoboken, NJ 07030 (US). BECKER, KURT, H.; Apartment 10B, 25 East 9th Street, New York, NY 10003 (US).</p> <p>(74) Agent: FRISCIA, Michael, R.; Friscia & Nussbaum, One University Plaza, Hackensack, NJ 07601 (US).</p>		<p>(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>With international search report.</i></p>

(54) Title: AC GLOW PLASMA DISCHARGE DEVICE HAVING AN ELECTRODE COVERED WITH APERTURED DIELECTRIC

(57) Abstract

A method and apparatus for stabilizing glow plasma discharges by suppressing the transition from glow-to-arc includes a perforated or apertured dielectric plate having an upper surface and a lower surface and one or more holes extending therethrough. The perforated dielectric plate (130) is positioned over the cathode (120). Each of the holes acts as a separate active current limiting microchannel that prevents the overall current density from increasing above the threshold for the glow-to-arc transition. This allows for a stable glow discharge to be maintained for a wide range of operating pressures and in a wide range of electric fields include DC and RF fields of varying strength. In another embodiment, the device comprises an AC glow plasma discharge device wherein an apertured dielectric is placed over an electrode. The apertured dielectric may have one or more apertures or capillaries extending therethrough.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

AC GLOW PLASMA DISCHARGE DEVICE HAVING AN ELECTRODE
COVERED WITH APERTURED DIELECTRIC

5

SPECIFICATION

BACKGROUND OF THE INVENTION

10

FIELD OF THE INVENTION

This invention generally relates to a method and apparatus for the suppression of the glow-to-arc transition in DC and RF glow discharges, and more specifically to a cathode configuration having a perforated or apertured dielectric covering for stabilizing glow plasma discharges. This invention also relates to a method and apparatus for suppression of the glow-to-arc transition in an AC circuit which requires matching the AC frequency to the characteristics of the apertured dielectric.

20

RELATED ART

A "plasma" is a partially ionized gas composed of ions, electrons, and neutral species. This state of matter is produced by high temperatures or strong electric fields either constant (DC) or time varying (e.g., R.F. or microwave) electromagnetic fields. Discharge plasmas are produced when free electrons are energized by electric fields in a background of neutral atoms / molecules. These electrons cause electron - atom / molecule collisions which transfer energy to the atoms / molecules and form a variety of species which may include photons; metastables, atomic excited states, free radicals, molecular fragments, monomers, electrons, and ions. The neutral gas becomes partially (or fully)

30

ionized and is able to conduct currents. The plasma species are chemically active and/or can physically modify the surface of materials and may therefore serve as the basis of new chemical compounds and may be used to modify existing compounds. Discharge plasmas can also produce useful amounts of optical radiation and can therefore be used in lighting. There are additionally —
5 many other uses for such plasmas. Glow discharges and arc discharges produce a class of plasmas known as current-maintained plasmas, since they are maintained by the passage of current therethrough. Such plasmas conduct only because current is passed therethrough and the conductivity falls off quickly if
10 the source of energy to the charge carriers is removed.

Transition points exist at which the various attributes of the discharge and discharge plasma change from the characteristics of a glow discharge to the characteristics of an arc discharge. The characteristics that distinguish arc from glow are a high gas temperature and a low cathode fall potential, though it is
15 also possible to have a high gas temperature associated with a high cathode fall and vice versa.

The transition from glow to arc passes through a series of stable or quasi-stable states. However, the final step from abnormal glow to arc is very often an unstable change, since a very large potential drop in the series resistance
20 would be required to make it stable. If there is no series resistance, the transition may take place very rapidly, without equilibrium being achieved in any intermediate stage. This transition becomes more rapid as the pressure of the background neutral gas increases towards atmospheric pressure.

In the past, there have been efforts to stabilize glow plasma discharges
25 in various ways such as the use of source frequencies over 1 kHz, insertion of a dielectric plate (or plates) between two metal electrodes and by using helium dilution gas. Additionally, other attempts to stabilize the glow plasma discharge include placement of an insulated plate on the lower electrode, use of a brush-style upper electrode, and the use of a metal upper plate in combination with an
30 insulating plate on the bottom thereof. However, there are certain drawbacks with these requirements in that, e.g. helium is expensive and there are physical

limitations based on the structure of the electrodes and the insulated plates.

Past work in this area include a series of articles by Okazaki, Satiko, et al., starting back in 1989 with the article by Kanazaw, S., et al., entitled, "Glow Plasma Treatment at Atmospheric Pressure for Surface Modification and Film Deposition," Nuclear Instruments and Methods in Physics Research (1989) — Elsevier Science Publishers, B.V. (North-Holland Physics Publishing Division), which disclosed a plasma treatment at atmospheric pressure to stabilize glow plasma by treatment in a gas which includes carbon-tetrafluoride (CF_4), using helium as the dilute gas and using an insulating plate on a lower electrode, and using a brush style electrode for the upper electrode to create a stable discharge at 3,000 Hz.

Yokoyama, T., et al., "The improvement of the atmospheric-pressure glow plasma method and the deposition of organic films," Journal of Physics (1990) IOP Publishing, Ltd., discloses an improved atmospheric pressure glow discharge plasma method for treating metallic substrates wherein the middle plate upper electrode is improved by use of an insulating plate set on its bottom.

Yokoyama, T. et al., "The mechanism of the stabilization of glow plasma at atmospheric pressure," Journal of Physics (1990) IOP Publishing, Ltd., discloses stabilization of a glow discharge of atmospheric pressure by controlling three conditions, namely, the use of a high frequency source, the use of helium gas for dilution, and the insertion of a dielectric plate between electrodes.

Okazaki, Satiko, et al., "Appearance of stable glow discharge in air, argon, oxygen, and nitrogen at atmospheric pressure using a 50 Hz source," Journal of Physics, (1993) IOP Publishing, Ltd., discloses a method and apparatus for stabilizing glow discharge by making the discharge occur in the early stages of the Kekez curve, and at a lower discharge breakdown voltage, by use of a metal wire mesh electrode.

Kogoma, Masuhiro, et al., "Raising of ozone formation efficiency in a homogeneous glow discharge plasma at atmospheric pressure," Journal of Physics (1994) IOP Publishing, Ltd., discloses an ozone formation apparatus for

increasing the efficiencies of ozone formation by use of a homogenous glow discharge at atmospheric pressure to create ozone efficiencies increased to about 10% in air to a maximum of 15% in oxygen over conventional filamentary current discharges in gas. The increase is attributed to better collision efficiency among electrons and molecules and to a lower increase in temperature
5 than in discharge filaments of a silent electric discharge.

Other work in this area includes U.S. Patent No. 4,698,551 to Hoag, entitled, "Discharge Electrode for a Gas Discharge Device," which uses pin-shaped electrodes which are effectively cooled in the glass flow and which
10 promote a stable glow-discharge.

U.S. Patent No. 5,387,842 dated February 7, 1995 to Roth, et al., entitled, "Steady-State, Glow Discharge Plasma," and U.S. Patent No. 5,414,324 dated May 9, 1995 to Roth, et al., entitled "One Atmosphere, Uniform Glow Discharge Plasma," both disclose a steady state glow discharge plasma
15 generated between a pair of insulated metal plate electrodes spaced up to five centimeters apart and energized with a RMS potential of 1 to 5 KV at 1 to 100 Khz. The space between the electrodes is occupied by a noble gas such as helium, neon, argon, etc., and it may also include air. The radio frequency amplifier means for generating and maintaining a glow discharge plasma
20 includes an impedance matching network. The arc of electric field is high enough to trap the positive ions of the plasma between the electrodes, but not so high that the electrons of the plasma are also trapped during a half cycle of the RF voltage.

None of these previous efforts disclose all of the benefits of the present
25 invention, nor does the prior art teach or suggest all of the elements of the present invention.

OBJECTS AND SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a method and apparatus for stabilizing glow discharge plasmas.

5 It is another object of the present invention to provide a method and apparatus for suppressing the glow-to-arc transition in glow discharges.

It is an additional object of the present invention to provide a method and apparatus to stabilize glow discharge plasmas in a constant electric field.

10 It is even an additional object of the present invention to provide a method and apparatus to stabilize glow discharge plasmas in time varying electric fields.

It is another object of the invention to provide a cathode configuration for stabilizing the cathode fall in a glow discharge.

15 It is an additional object of the present invention to provide a method and apparatus for suppressing the glow-to-arc transition for a wide range of operating conditions and a wide range of operating pressures.

It is another object of the present invention to provide a metal cathode covered with a perforated dielectric for suppressing the glow-to-arc transition and stabilizing glow discharge.

20 It is also an object of the present invention to provide a method and apparatus for suppressing the glow-to-arc transition for a wide range of electric field strengths.

It is an additional object of the present invention to tailor the characteristics of fuel combustion by field augmentation with suppression of the glow-to-arc transition.

25 It is an additional object of the present invention to tailor the characteristics of plasma assisted materials processing by suppressing the glow-to-arc transition in material processing.

It is another object of the present invention to suppress the glow-to-arc transition and to allow for large volume plasma work at atmospheric pressure.

30 It is an additional object of the present invention to reduce the complexity and costs of plasma processing of materials.

It is even a further object of the present invention to improve pollution control through the use of plasmas at high pressures by suppressing the glow-to-arc transition.

5 It is an additional object of the present invention to provide an AC glow plasma discharge device having an electrode covered with an apertured dielectric.

It is an additional object of the present invention to provide an AC glow plasma discharge device wherein an apertured dielectric is provided on one of the electrodes.

10 It is an additional object of the present invention to provide an AC glow plasma discharge device wherein an apertured dielectric covers one electrode and a solid dielectric is placed over the other electrode.

15 It is even an additional object of the present invention to provide an AC glow plasma discharge device wherein apertured dielectrics are provided over each of the opposing electrodes.

It is still an additional object of the present invention to provide an AC glow plasma discharge device wherein the dielectric contains at least one aperture.

20 It is still even an additional object of the present invention to provide an AC glow plasma discharge device wherein the apertured dielectric contains more than one aperture.

It is yet an additional object of the present invention to provide an AC glow plasma discharge device wherein the apertured dielectric contains a plurality of apertures.

25 It is even yet an additional object of the present invention to provide an AC glow plasma discharge device wherein the frequency of the AC current is adjusted according to the characteristics of the apertured dielectric.

30 It is still a further additional object of the present invention to provide an AC glow plasma discharge device wherein the frequency of the AC current is swept across a spectrum to determine the optimum frequency of the device for the characteristics of the apertured dielectric.

It is yet an additional object of the present invention to provide an AC glow plasma discharge device wherein the device transitions from a glow state to a capillary plasma electrode discharge state instead of an arc state.

5 These and other objects are achieved by the method and apparatus of the present invention for stabilizing glow plasma discharges by suppressing the transition from glow-to-arc. A dielectric plate having an upper surface and a lower surface and one or more of holes extending therethrough is positioned over the cathode and may be held in place thereon by a collar. Each of the holes or apertures or capillaries acts as a separate active current limiting micro-channel
10 that prevents the overall current density from increasing above the threshold for the glow-to-arc transition.

In one embodiment of the present invention, the device comprises an AC glow plasma discharge device wherein an apertured dielectric is placed over an electrode. The apertured dielectric may have one or more apertures extending
15 therethrough. The frequency of the AC source is adjusted to be matched to the characteristics of the apertured dielectric. At a proper frequency, jets come out of the apertures or capillaries, i.e. the capillaries get turned on and become electrodes to the opposite electrode. As such, the device is turned on and goes from a glow state to a capillary plasma electrode discharge state. A second
20 dielectric may be applied to the second electrode and the second dielectric may be solid or may be apertured.

BRIEF DESCRIPTION OF THE DRAWINGS

Other important objects and features of the invention will be apparent from the following Detailed Description of the Invention when read in context with the accompanying drawings in which:

5 **FIG. 1** is an exploded perspective view of the perforated dielectric covering a cathode of a DC embodiment of the present invention.

FIG. 2 is a schematic view of a circuit configuration for use with the present invention.

10 **FIG. 3** is a graph of voltage v. current for applied voltage, glow voltage, and arc voltage in Argon at 40 Torr.

FIG. 4 is a graph of voltage v. current for applied voltage, glow voltage, and arc voltage in Argon at 20 Torr.

FIGS. 5a and 5b are graphs of applied voltage, glow voltage and arc voltage with and without the perforated dielectric of the present invention.

15 **FIG. 6a** is a photograph showing an arc discharge and **FIG 6b** is a photograph showing a glow discharge.

FIG. 7 is a side plan view of another embodiment of the present invention for an RF field wherein perforated dielectrics are positioned over both electrodes.

20 **FIG. 8** is a side plan view of another embodiment of the present invention with an AC power source and an apertured dielectric positioned over one of the electrodes.

FIG. 9 is a side plan view of another embodiment of the present invention with an AC power source and apertured dielectrics positioned over
25 both electrodes.

FIG. 10 is a side plan view of another embodiment of the present invention with an AC power source and an apertured dielectric positioned over one of the electrode and a solid dielectric is placed over the other electrode.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a method and apparatus for stabilizing plasma glow discharges by suppressing the glow-to-arc transition in DC and RF electric field glow discharges which evolves from the cathode fall region. Referring to **FIG. 1**, it can be seen that a new cathode configuration —
5 has been developed to stabilize the cathode fall and suppress the glow-to-arc transition for a wide range of operating conditions. Accordingly, a stable glow discharge can be maintained with the cathode configuration of the present invention for a very wide range of operating pressures (up to atmospheric
10 pressures) and in a wide range of electric field strengths.

Referring to **FIG. 1**, which shows a DC embodiment, the cathode of the present invention, generally indicated at 10, comprises a metal cathode 20 (aluminum, stainless steel, etc.), covered with a perforated dielectric 30 positioned to face an upper electrode 40. The perforated dielectric 30 may be
15 retained on the cathode 20 by a collar 35 that fits over cathode 20 and has an aperture 36 therethrough, or may be formed as part of a cap or cover for the cathode 20, or may be positioned thereon and held in place thereon in any other manner known in the art.

Importantly, the apertured or perforated dielectric can be formed of any
20 desired dielectric type substance such as quartz, silicon nitride, silicon carbide, etc., even glass. The dielectric is preferably formed of a material that can withstand high temperatures. Essentially, a perforated dielectric comprises a sieve of holes of micron dimensions, although the apertured dielectric may include only one or more apertures or capillaries extending therethrough. The
25 center to center distance of the holes is of the same level of dimension. Hole dimensions are critical for particular applications. In trials discussed hereinafter, a dielectric having 10 micron holes with a center to center distance between the holes of 12 microns was used. Hole dimensions can vary from 5 to 200 μm for the hole diameter and from between 100 μm to 2 mm for the hole length

(thickness of the dielectric). Importantly, the ratio of the hole diameter to the dielectric thickness is an important factor and something that can be controlled depending upon the application. One example of such a ratio could be 10 to 1, the hole diameter being one-tenth of the thickness of the dielectric.

5 The perforated dielectric can be made by laser ablation. Blanks for dielectric plates made by Norton International can be used, and function in a desirable matter (a dielectric having a hole diameter of 10 μm , and a hole length of 0.6 mm). The hole diameter, hole lengths, hole density, and material can be varied to optimize the invention for a particular application. Any silicon carbide
10 wafer can be perforated by laser ablation to form a perforated dielectric for use in connection with the present invention.

Referring to FIG. 2, shows a circuit that has been used to conduct trials of the present invention that will hereinafter be discussed, which can be used with the cathode configuration of the present invention to effect a stable DC
15 glow plasma discharge. The circuit is governed by equation (1):

$$\text{Equation (1)} \quad V_s = I_1 (R_1 + R_2) = \frac{1}{R_1} (R_1 + R_2) V$$

$$\text{where} \quad I_2 = 4I$$

$$20 \quad R_E \approx \frac{R_3}{4} \quad (\text{for } R_1 \ll R_3)$$

$$V_g = V_s - I_g R_3$$

$$25 \quad V_d = V_s - I_d R_3$$

In this way, by measuring voltage V across resistor R, and current i through resistor R₁, we can calculate the voltage and the current across the
30 cathode 10.

The present invention allows DC glow discharges, which have a well known instability that limits the operating range, to operate at much higher pressure up to atmospheric pressures. Accordingly, this stabilization allows for

applications in many aspects of material processing, pollution remediation, novel lighting devices, and discharge-enhanced combustion.

5 The perforated dielectric covering the metal cathode stabilizes the cathode fall region of the DC discharge by breaking the discharge up into a large number of separate micro-channels. Each of the holes comprising the perforated dielectric acts as a separate, active current-limiting micro-channel. Particle losses due to wall effects and the finite volume of each channel place an upper limit on the electrical conductivity of each channel, and therefore place an upper limit on the current density that it can carry. This prevents the current density from increasing above the threshold for the glow-to-arc transition.

10 Additionally, it should be noted that a dielectric material could be directly deposited in a proper geometry directly onto a cathode by a vapor deposition or other process to apply the dielectric directly to the cathode. In this way, the cathode itself becomes an active current-limiting device.

15 A prototype DC glow discharge apparatus was set up using a parallel plate electrode arrangement in an Argon atmosphere of between 10-100 Torr, to illustrate the present invention. At these pressures, the phases of the glow-to-arc transition can be readily shown because the transition is sufficiently slow. The transition at atmospheric pressures occurs very rapidly and is difficult to observe. However, it should be pointed out that the present invention is designed to be used at pressures up to atmospheric pressures. Current voltage characteristics were recorded for a variety of operating conditions using a standard metal (Al) cathode. The measured curves show the well-known first transition corresponding to the breakdown of gas in the formation of a stable glow discharge, followed by a prominent second transition characteristic of the transition from the glow regime to an arc which creates a filamentary (high current density) channel. Subsequently, the conventional cathode was replaced by the new cathode design and the same current-voltage curves were recorded. All curves showed only the first transition to the stable high-current glow. No

indications of the previously observed glow-to-arc transition were found under any operating conditions. The spatial distribution of the discharge is also diffuse.

Referring now to FIG. 3, a graph of voltage vs. current for applied voltage (VG), glow voltage (Vg) and arc voltage (Vd) is shown for Argon at 40 Torr. FIG. 4 shows a graph of voltage vs. current for applied voltage (VG), glow voltage (Vg), and arc voltage (Vd) in Argon at 20 Torr.

FIGS. 5a and 5b are graphs of the applied voltage and glow-to-arc voltage with and without the perforated dielectric of the present invention. These figures show the stabilization of the glow plasma discharge. In a first Stage A, there is no current. In the second Stage B, voltage is applied, but current stays at zero. In a third Stage C, a glow discharge is achieved. As seen in FIG. 5a, the glow quickly goes to arc D, while in FIG. 5b, the perforated dielectric suppresses the glow-to-arc transition and stabilizes the glow discharge such that there is no arc.

FIG. 6a is a photograph showing an arc discharge which creates a filamentary (high current density) channel. FIG. 6b is a photograph showing a glow discharge characterized by a uniform glow discharge.

FIG. 7 is a side plan view of an RF discharge embodiment of the present invention wherein the perforated dielectric is positioned over both electrodes. As can be seen electrodes 120 and 140 are both covered by a perforated dielectric 130. Because the current reverses itself in a RF electric field, the dielectric 130 must be positioned over both electrodes 120 and 140, as both electrodes alternately serve as cathodes. By this configuration, the glow discharge can be sustained under broader operating conditions. Such a configuration results in a frequency independent and size independent device.

FIG. 8 is a side plan view of an embodiment of the present invention wherein there is an AC power source and one of the electrodes 220 is covered with a perforated or apertured dielectric 230. Importantly, the dielectric 230 can

contain one or more apertures or capillaries 232 as desired. The size, shape and positioning of the apertures 232 can be adjusted as desired. Each of the apertures or capillaries 232 allows for a capillary plasma electrode discharge 234 to extend therefrom. As can be seen in FIG. 8, the capillary plasma electrode discharge jets out of each aperture or capillary 232.

At a proper frequency, the discharge 234 jets out of the apertures or capillaries 232 to turn the device on. The proper frequency of the AC power source depends upon the properties of the apertured dielectric 230. Specifically, the size of the apertures or capillaries 232, the position of the apertures with respect to other apertures, the density of apertures, etc. The proper frequency can be determined by sweeping the frequency of the AC power source over a spectrum of frequencies. Upon achieving the proper frequency, the device is turned on as the device moves from glow state to capillary plasma electrode discharge state.

Referring to FIG. 9, a similar device to that of FIG. 8 is shown. In FIG. 9, two apertured dielectrics 230 are employed, one over each electrode 220 and 240 respectively. FIG. 10 shows a similar device to that shown in FIG. 9 in that a dielectric is placed over each electrode 220 and 240. However, in FIG. 10, one dielectric 230 is an apertured dielectric and the other dielectric 235 is not apertured, i.e. solid.

By applying the method and apparatus of the present invention to large volume plasmas at atmospheric pressures, it is possible to increase the energy released during combustion of fuels to levels several times higher than the Heating Value of the fuel. Efforts in this area in the past have failed because the distribution of energy is required over a substantial volume and cannot be concentrated in a small area. Because of the glow-to-arc transition, there has been tendency to produce arcs of a very high energy level with the rest of the volume remaining at a normal combustion level. By suppressing the glow-to-arc transition and stabilizing the plasma glow, the method and apparatus of the

present invention overcomes the limitations of the prior attempts and results in an enhancement of the combustion process resulting in much higher energy densities than could be previously achieved.

5 Additional applications of the present invention may occur in the field of air pollution remediation where stabilization of the glow-to-arc transition may — result in real time destruction of constituents of air emissions from manufacturing operations in remediation of soil and ground water pollution, in large volumes at high pressures. By suppressing the glow-to-arc transition and stabilizing the glow discharge, the present invention creates large volume
10 plasmas to destroy the polluting vapors at higher efficiencies with reduced cost. There could be additional applications relating to the destruction of combustion by-products such as NO_x and SO_x which have heretofore been destroyed by pulsed corona and barrier discharges.

The present invention is additionally applicable to the cleaning of
15 lithography sheet surfaces in atmospheric pressures. Additionally, there may be possible utility for large area surface cleaning at atmospheric pressure for curing polymer films. By being able to operate at atmospheric pressure, a great advantage is achieved over the high processing cost required in a vacuum process. Additionally, the present invention can be used for pretreatment of
20 semi-conductors, glasses, and polymers which are to be used for direct metal ion beam processing.

Additionally, an atmospheric pressure glow discharge plasma can be used to sterilize biologically contaminated surfaces. Current techniques in this area utilize high temperatures, strong chemicals, and/or ultraviolet radiation to
25 sterilize contaminated items. However, there are problems with these approaches in that the processes are time intensive and potentially hazardous and result in the formation of potentially hazardous by-products. It has been demonstrated that materials exposed to a one-atmosphere pressure glow discharge plasma can be sterilized of biological contaminants in under one

minute.

Having thus described the invention in detail, it is to be understood that the foregoing description is not intended to limit the spirit and scope thereof. What is desired to be protected by the Letters Patent is set forth in the appended

5

claims. —

CLAIMSWhat is claimed is:

1. A glow plasma discharge apparatus for generating and maintaining a glow plasma discharge comprising:
 - 5 a pair of electrodes positioned in facing relation having a space — therebetween;
 - a dielectric placed over one of the electrodes to partially occupy the space;
 - at least one aperture formed in the dielectric; and
 - 10 an electric field generated between the electrodes.
2. The apparatus of claim 1 wherein the apertured dielectric comprises a plurality of apertures.
3. The apparatus of claim 2 wherein the apertured dielectric comprises apertures having a diameter ranging from 5 to 200 μ m.
- 15 4. The apparatus of claim 2 wherein the apertured dielectric is between 100 μ m and 2mm in thickness.
5. The apparatus of claim 1 wherein a second dielectric is placed over the other of the electrodes.
6. The apparatus of claim 5 where in the second dielectric has at least on
20 aperture.
7. The apparatus of claim 6 wherein the second dielectric has a plurality of apertures.
8. The apparatus of claim 5 wherein the second dielectric is solid.
9. The apparatus of claim 7 wherein the apertures have a diameter in the
25 range of 500 to 200 μ m.
10. The apparatus of claim 9 wherein the second dielectric is between 100 μ m and 2mm in thickness.
11. A glow plasma discharge apparatus for generating and maintaining a glow plasma discharge comprising:

a pair of electrodes positioned in facing relationship;
a dielectric having at least one aperture placed over one of the electrodes;
an AC power source; and

5 wherein, the frequency of the AC power source is tuned to the
characteristics of the apertured dielectric to turn on the apparatus.

12. The apparatus of claim 11 wherein the apertured dielectric comprises a
plurality of apertures.

13. The apparatus of claim 12 wherein the apertured dielectric comprises
apertures having a diameter ranging from 5 to 200 μ m.

10 14. The apparatus of claim 12 wherein the apertured dielectric is between
100 μ m and 2mm in thickness.

15. The apparatus of claim 11 wherein a second dielectric is placed over the
other of the electrodes.

15 16. The apparatus of claim 15 where in the second dielectric has at least on
aperture.

17. The apparatus of claim 16 wherein the second dielectric has a plurality
of apertures.

18. The apparatus of claim 15 wherein the second dielectric is solid.

19. The apparatus of claim 17 wherein the apertures have a diameter in the
20 range of 500 to 200 μ m.

20. The apparatus of claim 19 wherein the second dielectric is between
100 μ m and 2mm in thickness.

21. A method of creating a plasma discharge device comprising:
providing electrodes positioned in facing relationship;
25 interconnecting an AC source between the electrodes;
covering one of the electrodes with an apertured dielectric;
powering the AC power source; and
adjusting the frequency of the AC power source to turn on the device.

22. The method of claim 21 wherein the apertured dielectric is formed by forming an aperture in a dielectric.
23. The method of claim 21 wherein the apertured dielectric is formed by forming a plurality of apertures in a dielectric.
- 5 24. The method of claim 21 wherein the step of adjusting the frequency of — the AC power source comprises sweeping the frequency over a spectrum of frequencies until the device turns on.
25. The method of claim 21 further comprising covering the other of the electrodes with an apertured dielectric.
- 10 26. The method of claim 21 further comprising the step of covering the other of the electrodes with a solid dielectric.

1/6

FIG. 1

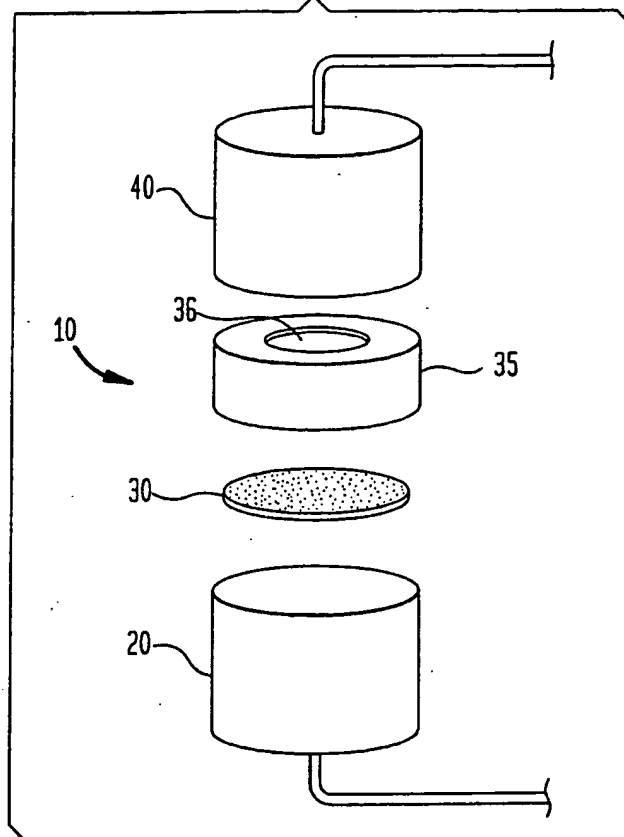
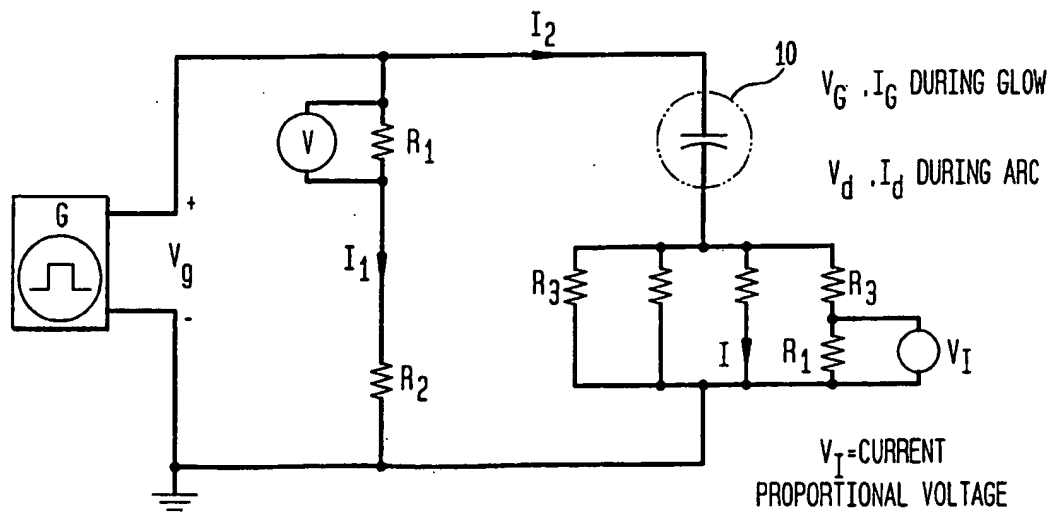


FIG. 2



2/6

FIG. 3

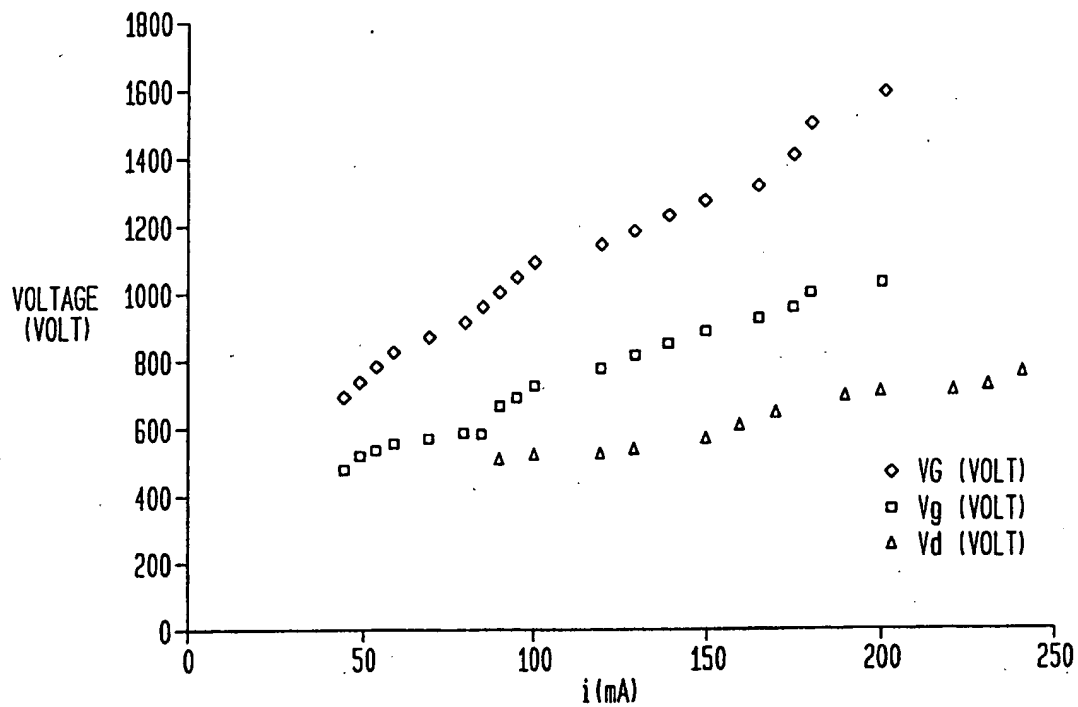
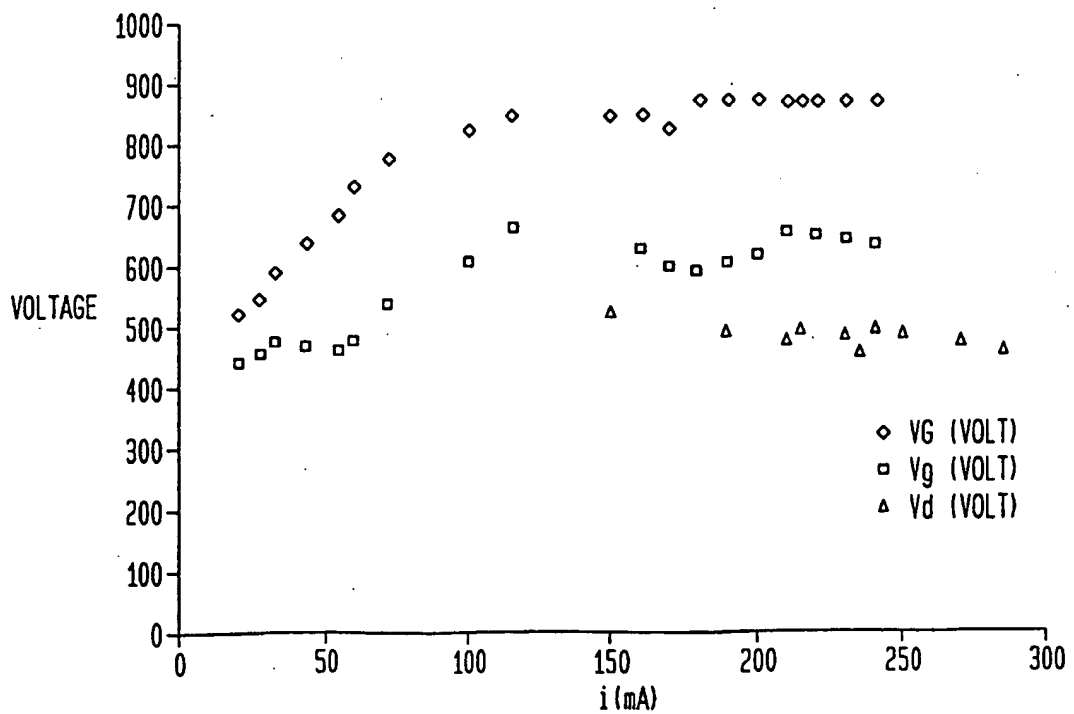


FIG. 4



3/6

FIG. 5A

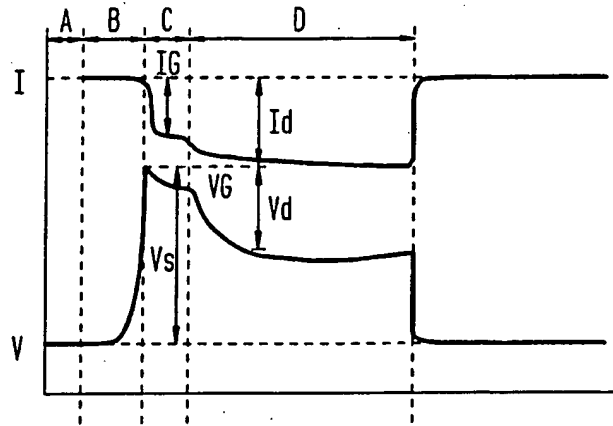


FIG. 5B

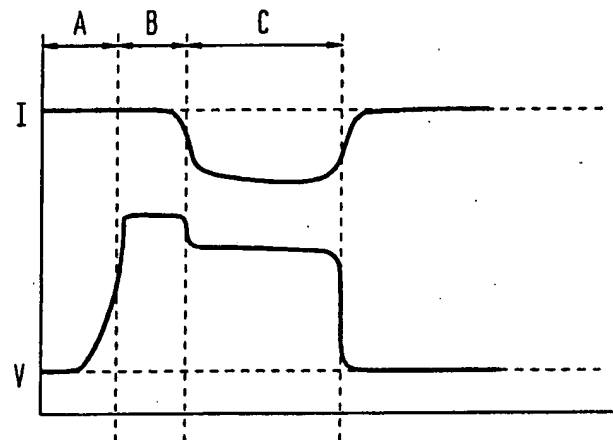
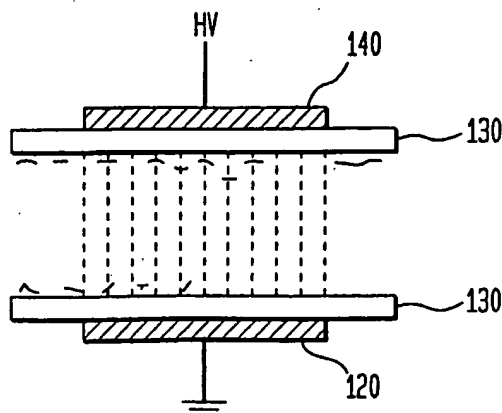


FIG. 7

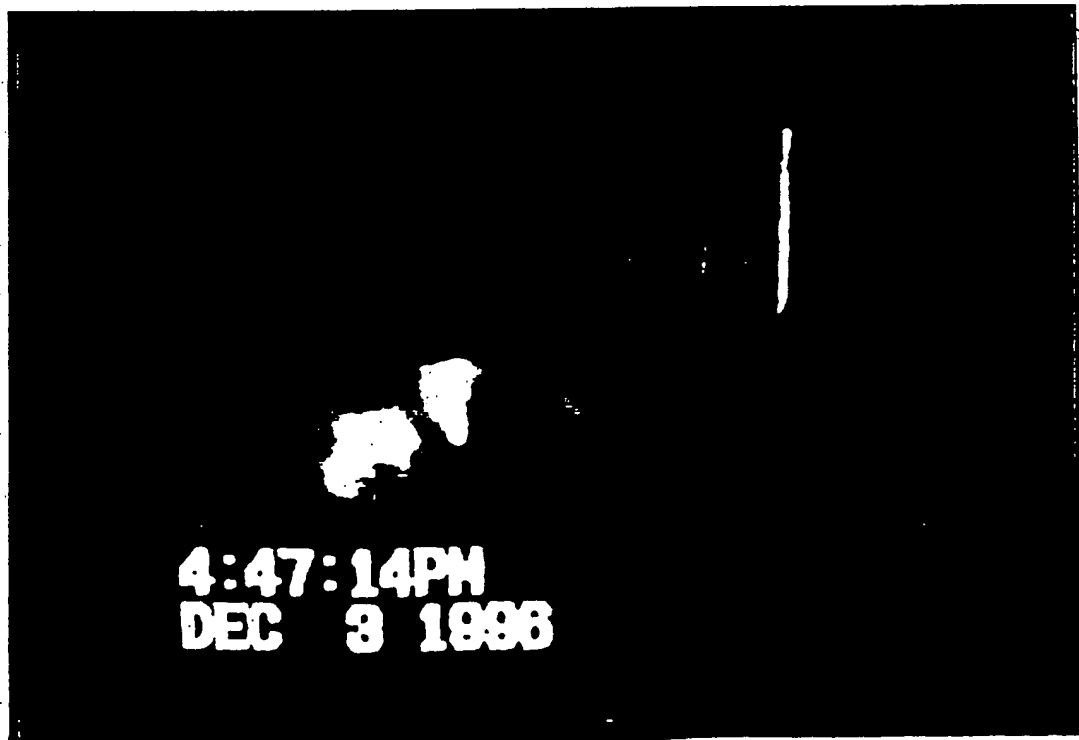


4/6

FIG. 6A



FIG. 6B



5/6

FIG. 8

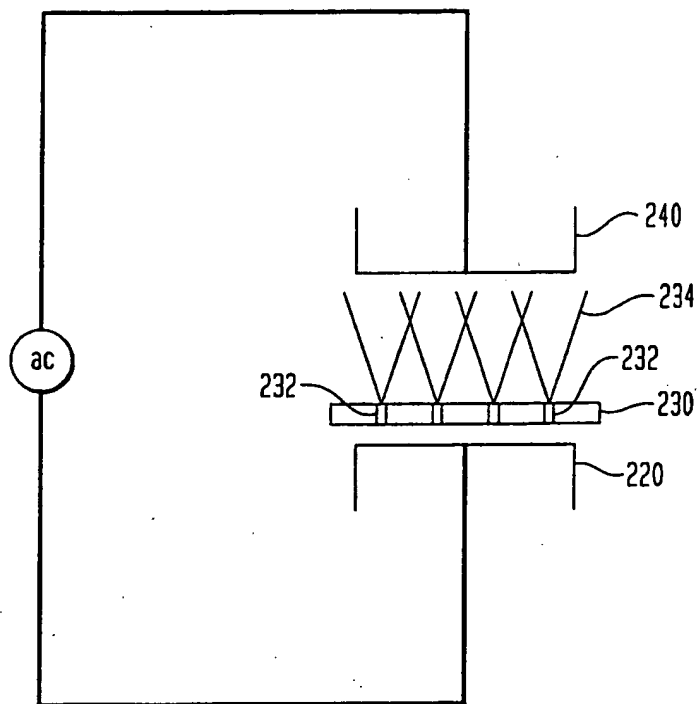


FIG. 9

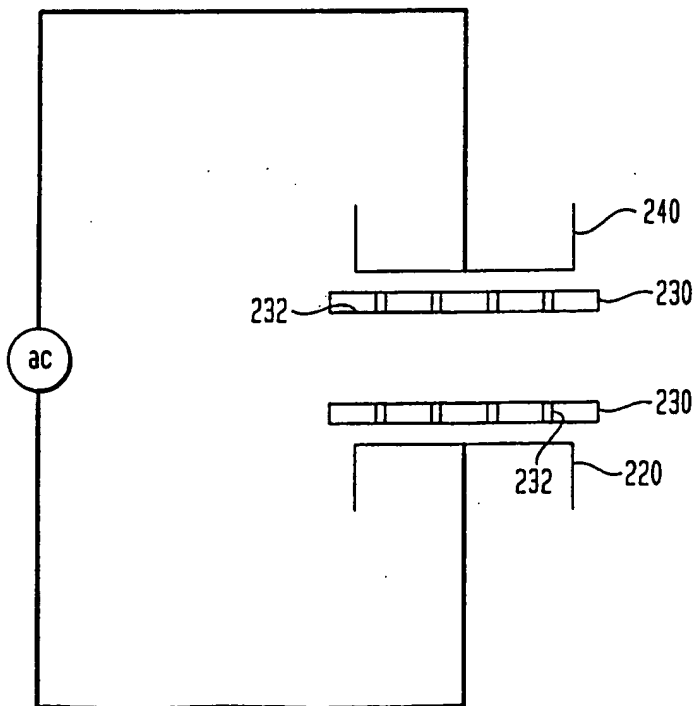
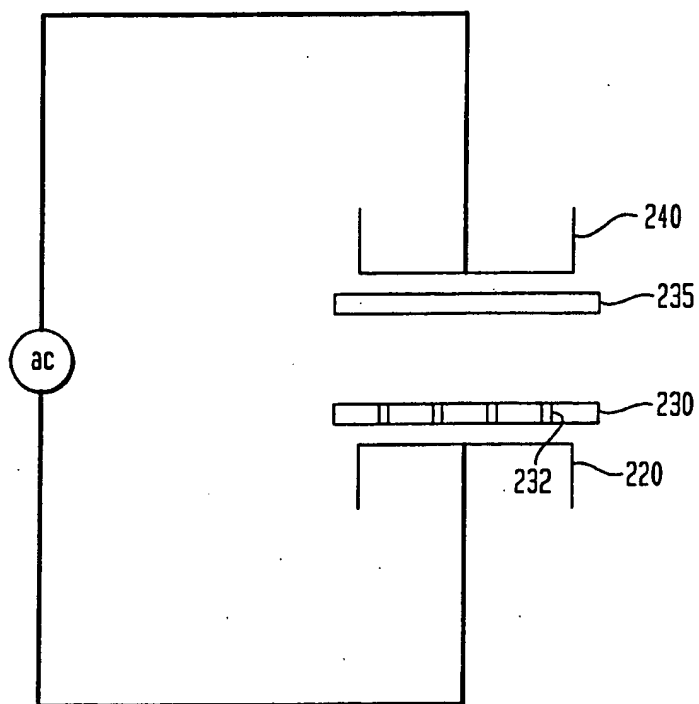


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/21147

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01J 17/49

US CL :313/582,583,586,619

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 313/582,583,586,619

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,914,642 A (CODERRE et al.) 21 October 1975 (21.10.75), col. 1, lines 66 - col. 2, line 42	1, 2, 5, 7, 11, 12, 15, 16, 17, 21-26
P, X	US 5,872,426 A (KUNHARDT et al.) 16 February 1999 (16.02.99) entire document	1-26

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

26 NOVEMBER 1999

Date of mailing of the international search report

16 DEC 1999

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

NIMESHKUMAR PATEL

Telephone No. (703) 305-4794